Testing the transport Energy Environmental Kuznets Curve hypothesis in the EU27 countries

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Abstract

Transport activities are essential for economic and social development. But the transport sector has also shown the fastest growth in energy consumption in the European Union and its contribution to increasing greenhouse gas emissions merits the thorough attention of academics and policy-makers. In this paper, the relationship of economic growth and transport activities with transport final energy consumption is analyzed. Energy Kuznets curves are estimated for a panel data set covering 27 EU countries in the period 1995-2009 for total transport energy use, household transport energy use, and productive transport energy use (all three in absolute and per capita energy use terms). Productive transport energy use and gross value added relationship is further considered as per hours worked. Finally, the control variables of energy prices and differences in the economic structures are tested. Empirical results show that the elasticity of transport energy use respect to gross value added in per capita terms decreases from a threshold for the three transport energy consumption variables, but the turning point of improved environmental quality is not reached in any instance.

Keywords: Energy, Sustainability, Kuznets Curve, Transport, EU27-countries

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Abstract

Transport activities are essential for economic and social development. Nevertheless, the transport sector has also shown the fastest growth in energy consumption in the European Union and its contribution to increasing greenhouse gas emissions merits the thorough attention of academics and policy makers. In this paper we analyze the relationship of economic growth and transport activities with transport final energy consumption. Energy Kuznets curves are estimated for a panel data set covering the EU27 countries in the period 1995-2009 for total transport energy use, household transport energy use, and productive transport energy use (all three in absolute and per capita energy use terms). The productive transport energy use and gross value added relationship is further considered as per hour worked. Finally, the control variables of energy prices and differences in the economic structures are tested. Empirical results show that the elasticity of transport energy use with respect to gross value added in per capita terms decreases from a threshold for the three transport energy consumption variables, but the turning point of improved environmental quality is not reached in any instance.

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1. INTRODUCTION

European Union (EU) Member States have been implementing energy saving policies to reach the objective of reducing energy consumption by 20% in 2020. Worldwide, programs targeting reduced energy consumption in different sectors stress the need for integrated strategies to address the multiple problems associated with energy use. Clearly, transportation activities are critical to the overall success of these approaches. According to Eurostat data (2015), transport represented 31.8% of the final end use of energy in the EU-28 in 2012, followed by households and industry, with 26.2% and 25.6%, respectively. Moreover, transport is the sector with the fastest-growing energy consumption and greenhouse gas (GHG) emissions in the EU, despite advances in transport technology and the post 2007 economic activity slowdown. Nevertheless, there are significant differences between transport modes and countries. International aviation and road transport are the modes with the highest growth in energy consumption between 1990 and 2012, and energy consumption has grown particularly quickly in the new EU Member States from Central and Eastern Europe. Indeed, the share of the transport sector has increased by at least 10 points in Bulgaria, Poland and Slovenia, due to both the reduction of industrial energy consumption and the rapid rise in car ownership (ADEME, 2012).

Transport energy consumption growth has caused transport related CO_2 emissions to rise by 21% since 1990 and 2.5% since 2000 (ADEME, 2012), whereas in other sectors these emissions are below their 1990 levels (Skinner et al., 2010). As a result, in 2012 transport activities accounted for a growing share of the total emissions, with road transport accounting for more than two thirds of total transport emissions and about one fifth of the EU's total CO_2

emissions (European Commission, 2014). Overall, the transport sector is responsible for around a quarter of EU GHG emissions, making it the second highest emitting sector after energy.

To reduce energy use and decouple pollutant emissions from economic growth, the EU has put policies in place to reduce emissions and improve energy efficiency. In fact, in recent decades economic growth has boosted international trade to unprecedented levels and become critical to the world economy. In addition, the emerging market economies of developing countries such as Brazil, China and India have increased global trade flows (Neto et al., 2014), and consequently affected transport activities and energy demand.

The aim of this paper is to analyze the relationship between economic activities and growth and the transport final energy consumption in the EU countries. For this, transport energy-environmental Kuznets curves were estimated for panel data of 27 EU countries over the 1995-2009 period.

The environmental Kuznets curve (EKC) hypothesis states that there is an increasing relationship between economic growth and environmental pressure until some turning point in income per capita, after which further increases in income lead to improved environmental quality (Chowdhury and Moran, 2012). The potential validity of the EKC hypothesis has been extensively tested, in most cases for the economy as a whole. However, for a significant body of literature, EKC empirical evidence is still open to question and the results are frequently not robust to various changes in the specification of the econometric model (see, e.g. surveys by Dinda, 2004; Stern, 2004; Kaika and Zervas 2013a; 2013b). Similarly, studies applied to a sector-level analysis have not resolved the ambiguity in empirical evidence (Fujii and Managi, 2013). These authors empirically tested the CO_2 EKC hypothesis for nine industries and found an N-shaped trend for total CO_2 emissions with increasing income, but the EKC hypothesis was supported for three out of the nine sectors (“paper, pulp and printing”, “wood and wood products" and "construction" industries). Regarding the more specific case of EKC studies on the transport sector, i.e. the analysis of the relationship between transport energy consumption (and corresponding CO_2 emissions) and economic growth, Cole et al. (1997) and Hilton and Levinson (1998) have confirmed the EKC hypothesis for pollutants from the transport sector in several countries. However, Cox et al. (2012) found no evidence of an EKC for household transport emissions in six case study areas in Scotland, and Chandran and Tang (2013), Abdallah et al. (2013) and Azlina et al. (2014) concluded that the inverted U-shaped transport energy EKC hypothesis is not valid in the ASEAN-5, Tunisian and Malaysia economies.

Multiple approaches have been considered, too, for the indicators used to measure the environmental pressures (Arbex and Perobelli, 2010; Beça and Santos, 2014). Suri and Chapman (1998), Agras and Chapman (1999), Stern (2004), Luzzati and Orsini (2009) and Ahmed and Long (2012) are among the researchers who have used energy consumption as an indicator of environmental pressure, which has propagated the term "energy-environmental Kuznets curve". Accordingly, the standard regression model relates this environmental quality dimension to the gross domestic product per capita (GDPpc), usually in natural logarithms and its squared and cubic value.

This study contributes to the literature by focusing on a key economic sector that has shown the most intense energy consumption growth in the EU and is among the highest contributors to CO_2 emissions from fuel combustion. First, we estimated the energy-environmental Kuznets curve for total transport and then we did so for household transport. Finally, two other energy-environmental Kuznets curves were estimated, for transport energy use in production processes with respect to gross value added (GVA) in per capita terms and in hours worked, respectively. The latter relates economic productivity growth to productive transport energy use and evaluates transport production efficiency. To the best of our knowledge, this is the first work to assess the transport energy EKC hypothesis by decomposing the transport sector into the transport used by households and in production processes. Additionally, the consideration of transport energy use and GVA in terms of the number of hours worked (rather than the usual per capita measure) is pioneering in the analysis of the EKC, and provides more specific operational guidance for transport policy making.

The paper is organized as follows. Section 2 specifies the data sources used and Section 3 explains the methodology. In Section 4, the transport energy EKCs estimation results are presented and the elasticity values calculated from these estimations are analyzed. The main results are also discussed. The conclusions of the study are in Section 5.

2. DATA

The data in this study came from two main sources. The main source is the World Input-Output Database (WIOD) (WIOD, 2015; Dietzenbacher et al., 2013; Timmer et al., 2015). The WIOD is divided into four large sub-databases for each country: World Input-Output Tables, National Input-Output Tables, Socio-Economic Accounts and Environmental Accounts. The second source is the International Energy Agency (IEA) database (2015). This database provides energy statistics of all kinds, including for supply, trade, stocks, production and demand, broken down by a large number of countries, from 1990 to 2011.

Finally, given the data available from these main sources, this study covers 27 EU countries (Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden, Spain, and the UK). The time period studied covers the years 1995 to 2009, due to the lack of data continuity for the years 2009 to 2011, for all the variables considered.

2.1 Gross Value Added

Gross value added (GVA) came from the WIOD Socio-Economic Accounts sub-base. These data are available by country at current basic prices in national currency. Thus, they were adjusted for the relevant price levels and exchange rates. The figures are in thousands of 1995 constant US dollars and converted into natural logarithms.

2.2 Energy

Total final energy consumption can be broken down into industry, transport, other (including agricultural and forestry, fishing, commercial and public services, residential and non-specified total energy use) and non-energy uses. Transport energy use can be further broken down into two large categories: transport energy used in production processes and transport energy used by households. Household transport energy use can be obtained as a difference between household energy use from the WIOD and residential energy use from the IEA database. Once household transport energy use is computed, productive transport energy use can be estimated as the difference between total transport energy use and households transport energy use. Productive transport energy use includes inland, water, air and other transport energy use. Other transport energy use refers to use by other sectors of the economy (e.g. transport activities in the agricultural sector).

The data for total transport energy use and total residential energy use come from the IEA 2015 database and the information on households comes from the WIOD Environmental Accounts database (WIOD, 2015). These variables are expressed in tons of oil equivalent (toe) and converted into natural logarithms.

2.3. Population and worked hours

Population data are from the Eurostat database. The figures are in millions of persons on 1 January each year. The worked hours are from the WIOD Socio-Economic Accounts subdatabase. The figures are in millions of hours worked by persons engaged in the economy and converted into natural logarithms.

2.4. Share of agricultural employment and prices

The share of agricultural employment in the total national employment for each country has been calculated using data from the WIOD Socio-Economic Accounts database (WIOD, 2015), to represent the possible effect of the different economic structures for each country. Prices are from the Eurostat (2015) database, expressed as the annual rate of change in liquid fuels and fuels in harmonized consumer price indices, which is analogous to logarithm differences of the indices' values.

2.5. Descriptive analysis

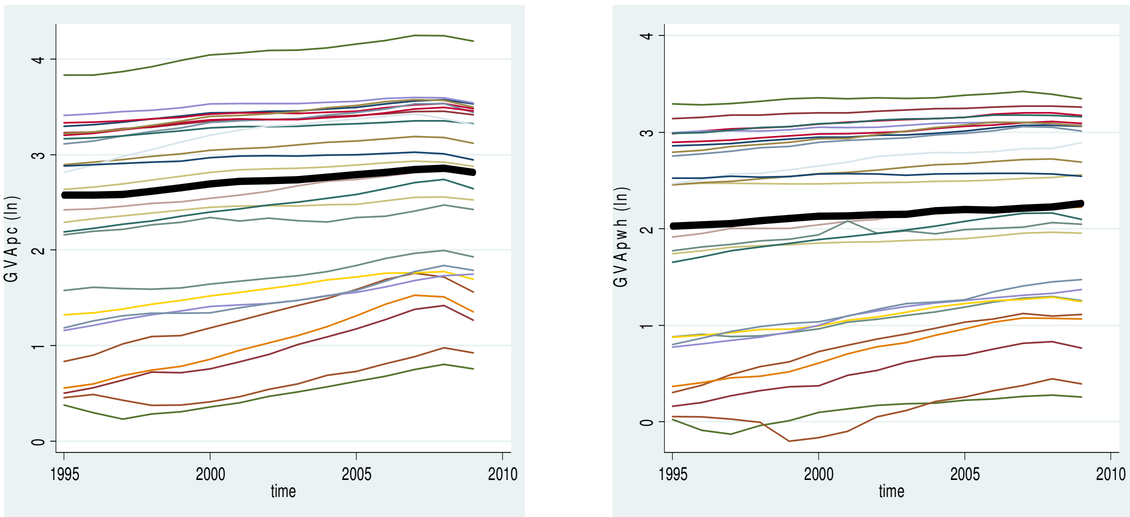
Table 1 shows the main descriptive statistics of the study variables: gross value added per capita (GVApc), gross value added per hour worked (GVAphw), Transport energy use, Household transport energy use and Productive transport energy use. All variables are expressed in Napierian logarithms. Table 1 also shows the *overall* statistics (which refer to the whole sample), the *within* statistics (which refer to the variation from each country's average), and the *between* statistics (which refer to the standard deviation, and minimum and maximum of the averages for each country). If a variable does not change over time, its *within* standard deviation will be zero. Table 1 shows that the typical standard deviation of the data is higher across countries than over time.

Table 1. Descriptive Statistics

Variable (Napierian logarithms)		**Mean**	**Std. Dev.**	**Min**	**Max**	**Observations**
Total transport energy use	*overall*	8.430123	1.44256	4.574711	11.01388	N = 405
	between		1.458377	5.038041	10.94907	i = 27
	within		0.16679	7.860988	8.897413	t =15
Household transport energy use	*overall*	7.587089	1.487098	3.688763	10.44999	N = 405
	between		1.506641	4.089488	10.29753	i = 27
	within		0.1419689	7.108035	8.003479	t = 15
Productive transport energy use	*overall*	7.832558	1.44499	3.484196	10.42382	N = 405
	between		1.450698	4.465283	10.19769	i = 27
	within		0.2374902	6.101657	8.649954	t = 15
GVApc	*overall*	2.464663	1.015421	0.2317152	4.245906	N = 405
	between		1.020962	0.4947985	4.059074	i = 27
	within		0.1575997	1.964998	2.950794	t = 15
GVApwh	*overall*	2.027885	1.019055	-0.200030	3.421529	N = 405
	between		1.028115	0.1212105	3.348867	i = 27
	within		0.1344756	1.527934	2.354183	t = 15

Figure 1 shows, from left to right, the Naperian logarithm values of GVApc and phw for each country (represented by different lines), from 1995 to 2009. Therefore, a positive slope involves exponential growth. The values are spread around the thick black line that represents each year's average value.

Figure 1. GVApc and GVAphw for each EU country (1995-2009)

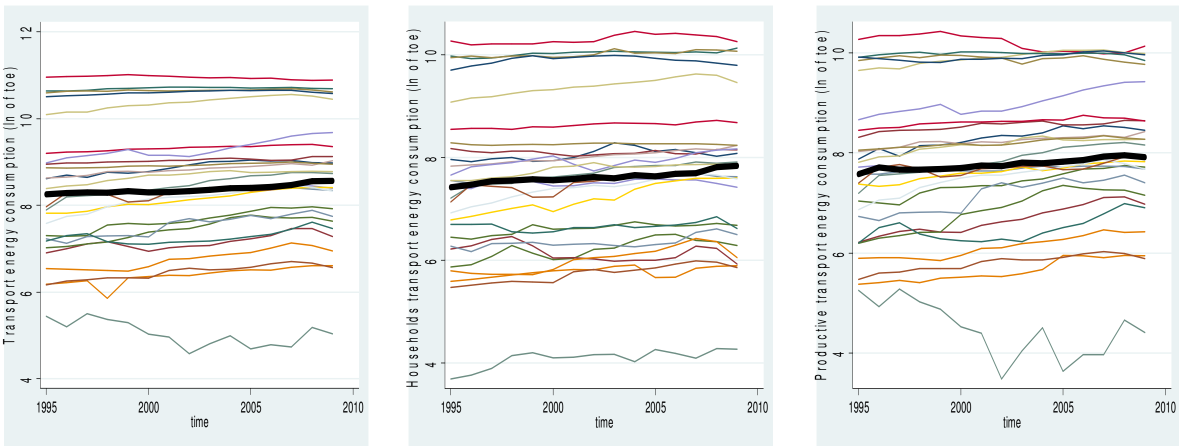


The graphs show that both GVApc and GVAphw (in Naperian logs) have a slightly positive growth rate over the period, contrasting with large differences between countries.

Further, both graphs show that countries with lower GVApc and GVAphw (Bulgaria, Romania, Latvia, Lithuania, Poland and Estonia) have more of an upward trend. On the other hand, countries with the highest levels of GVApc and GVAphw (Luxembourg, Denmark, Belgium and Germany), have a much smoother upward trend. Additionally, Figure 1 shows a pronounced decrease in GVApc in 2009, reflecting the deep recession that gripped most European countries.

Figure 2 shows, from left to right, the evolution of Transport, Household transport and Productive transport energy use. The graphs also show that there are large differences between countries. Countries with the highest Transport energy use are France, Germany, Italy, Spain and the UK, while those with the lowest are Cyprus, Malta and Estonia. Additionally, Bulgaria, Slovenia, Latvia and Lithuania show a higher upward trend until 2008, followed by a rapid decrease in 2009 (as shown in ADEME, 2012). Poland also shows high energy consumption growth since 2002.

Figure 2. Total, Household and Productive Transport energy use for each EU country (1995-2009)



3. METHODOLOGY

The general specification to test the different EKC types is expressed as follows:

$$E_{it} = A_{it} + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Y_{it}^3 + e_{it} \qquad [1]$$

where E stands for a measure of environmental pressure in logarithms (in this study, total, household or productive transport energy consumption), Y is the independent variable of income per capita or other similar variable in logarithms (in this study GVA per capita or per hour worked (GVApc or GVAphw)), A represents the sum of an annual temporal effect common to all countries or regions (time effect) and an individual effect constant for each country (country effect), and i and t denote countries and years, respectively. Finally, e is a random error term.

If the EKC exists then the turning point can be calculated by making the energy (E) elasticity with respect to Y equal to zero. Therefore, the elasticity values provide valuable insights to analyze the Kuznets curve hypothesis and relevant policy interpretations. If $\beta_1>0$, $\beta_2<0$ and $\beta_3 \leq 0$, the turning points hold where the elasticity is equal to zero. Positive elasticity values show that energy consumption increases when Y does. If it is higher than one, then energy is increasing more than proportionally. Negative values show that energy decreases when Y increases. Thus, the Kuznets curve hypothesis fully holds when elasticity is zero and changes from positive to negative values.

The elasticity of E (transport energy consumption or others, as appropriate) with respect to Y (GVA per capita or per hour worked, as appropriate) for each EU country and year, may be obtained as follows:

$$ela_{it} = \beta_1 + 2\beta_2 Y_{it} + 3\beta_3 Y_{it}^2 \qquad [2]$$

In previous studies, environmental indicators have been taken either in absolute or per capita terms. Per capita terms are used in most of them, while absolute terms have been taken mainly to reflect total human pressure (Luzzati and Orsini, 2009). To test the transport energy EKC hypothesis we have used both absolute and per capita transport energy consumption as proxies for the environmental impacts of transport.

Other variables that may affect *E* are often included in the EKC model specification. Nevertheless, as stated by Kaika and Zervas (2013a), the model [1] usually varies depending on the study, so as to best fit the available data and its overall objective.

Therefore, a control variable (C) has been included in [1] to express the share of agricultural employment in the total national employment for each country (WIOD, 2015). This variable represents the possible effect of the different economic structures of each country. Previous studies, such as those by Perrings and Ansuategi (2000) and Friedl and Getzner (2003), have adopted a similar procedure. The EKC has been estimated including this control variable and the results are compared.

An indicator of energy prices (P) has also been included in equation [1]. According to Rodriguez et al. (2016), this variable is relevant as energy price changes may move the EKC. The authors state that energy price increases can produce substitution effects, boost investment in energy efficiency and reduce energy consumption. Nevertheless, only a few studies exploring the EKC hypothesis have included energy prices. Of these, we should mention Agras and Chapman (1999) and Richmond and Kaufmann (2006). As stated by Rodriguez et al. (2016), one of the main reasons for the scarcity of studies that include energy prices is the glaring lack of available data for some energy sources. We have estimated the EKC curve with and without a price variable and the results are compared.

Multicollinearity problems among variables have been noted in Narayan and Narayan (2010: 661) when variables are included in the squared and cubic form, as in [1]. Therefore, values for variance inflation factors (VIF) have been analyzed to quantify the severity of multicollinearity among squared and cubic form variables in the regression analysis. In general, for each explanatory variable it is suggested that the VIF should not exceed the value of 10, which is equivalent to a value of 0.1 for the tolerance indicator (1/VIF). Nevertheless, more stringent criteria recommend a maximum VIF of 5, equivalent to 0.2 for the tolerance indicator (Pablo-Romero et al., 2015; Sánchez-Braza and Pablo-Romero, 2014). The VIF values obtained in this study are given in Table 2, showing values higher than 10. Therefore, for each explanatory variable, data has been converted to deviations from the geometric mean of the sample. In general, as shown in Table 2, it was found that the VIF values do not exceed 5. It is worth noting that making these data conversions implies that now β_1 is the transport energy consumption elasticity with respect to income per capita, in the central point of the sample (De la Fuente, 2008; Pablo-Romero and Sánchez-Braza, 2015).

Table 2. Variance inflation factors (VIF)

	Y = GVApc		**Y = GVApwh**	
Variable	VIF (variables)	VIF (deviations from the geometric mean)	VIF (variables)	VIF (deviations from the geometric mean)
Y	204.42	2.72	133.23	1.97
Y²	969.77	1.79	762.72	2.47
Y³	319.80	3.22	298.90	3.48

Additionally, unit root tests were used to examine the stochastic nature and properties of the variables. First, any cross-sectional dependence in the data was tested using the parametric testing procedure proposed by Pesaran (2004), under the null hypothesis of cross-sectional independence. Table 3 shows that, at a 1% significance level, the null hypothesis of cross-sectional independence in our panel is rejected for all series.

Table 3. Panel cross-sectional dependence tests

Energy variables	CD test	Income variables	CD test	Control variables	CD test
Total Transport Energy *(absolute)*	30.53***	***Y*** *(GDPpc)*	53.76***	***C***	37.89***
Total Transport Energy *(per capita)*	21.16***	$\boldsymbol{Y^2}$ *(GDPpc)*	55.35***	***P***	45.59***
Household Transport Energy *(absolute)*	23.44***	$\boldsymbol{Y^3}$ *(GDPpc)*	52.88***		
Household Transport Energy *(per capita)*	14.80***	***Y*** *(GDPphw)*	51.51***		
Productive Transport Energy *(absolute)*	20.48***	$\boldsymbol{Y^2}$ *(GDPphw)*	51.08***		
Productive Transport Energy *(per capita)*	16.79***	$\boldsymbol{Y^3}$ *(GDPphw)*	50.03***		
Productive Transport Energy *(per hour worked)*	12.34***				

*Note: *** denotes significance at the 1% level.*

Second, considering the cross-sectional dependence, the cross-section augmented Dickey-Fuller (CADF) test suggested by Pesaran (2007), which is an extension of the cross-sectionally augmented IPS (CIPS) test of Im et al. (2004), was used. The statistic of the Pesaran CIPS test was constructed from the results of panel-member-specific ADF regressions where cross-sectional averages of the dependent and independent variables are included in the model. So, the Pesaran CIPS test is suitable to test for unit roots in heterogeneous panels with cross-sectional dependence. Under the null hypothesis of nonstationarity, the test statistic has a non-standard distribution.

Table 4 shows the results of the panel unit root tests in the presence of cross-sectional dependence, applied to the variables in levels and first differences. The appropriate lag order for the CADF regressions underlying the Pesaran CIPS test was determined by means of auxiliary ADF test regressions for each of the cross-sectional units run. The optimal lag length for the unit root test was determined using the Ng-Perron sequential t-test (Ng and Perron, 1995). Once the individual lag lengths were determined, the CIPS test based on CADF-regressions with the respective previously determined lag lengths was applied. The truncated version of the test was then applied, which limits the undue influence of extreme values that could occur when the time dimension is small. Test results show that all variables are I(1), as they are stationary in first differences and nonstationary in levels.

Table 4: Pesaran CIPS panel unit root test in the presence of cross-sectional dependence

Variables	Level		First Differences	
	intercept	intercept and trend	intercept	intercept and trend
Total Transport Energy *(absolute)* *(Avg. lags)*	-1.660 (0.54)	-1.632 (0.54)	-2.620*** (0.18)	-3.341*** (0.18)
Total Transport Energy *(per capita)* *(Avg. lags)*	-1.781 (0.54)	-1.848 (0.54)	-2.569*** (0.18)	-3.372*** (0.18)
Household Transport Energy *(absolute)* *(Avg. lags)*	-1.771 (0.36)	-1.783 (0.36)	-2.452*** (0.54)	-3.081*** (0.54)
Household Transport Energy *(per capita)* *(Avg. lags)*	-2.143* (0.45)	-1.858 (0.45)	-2.307*** (0.59)	-3.190*** (0.59)
Productive Transport Energy *(absolute)* *(Avg. lags)*	-2.021 (0.31)	-2.135 (0.31)	-2.804*** (0.04)	-3.100*** (0.04)
Productive Transport Energy *(per capita)* *(Avg. lags)*	-2.057* (0.50)	-2.195 (0.50)	-2.769*** (0.04)	-3.121*** (0.04)
Productive Transport Energy *(per hour worked)* *(Avg. lags)*	-2.119 (0.31)	-2.185 (0.31)	-2.970*** (0.04)	-3.248*** (0.04)
Y *(GDPpc)* *(Avg. lags)*	-2.021 (0.81)	-2.267 (0.81)	-2.273** (0.54)	-2.636** (0.54)
$\boldsymbol{Y^2}$ *(GDPpc)* *(Avg. lags)*	-1.439 (0.86)	-1.689 (0.86)	-2.996** (0.40)	-2.623** (0.40)
$\boldsymbol{Y^3}$ *(GDPpc)* *(Avg. lags)*	-1.306 (1.00)	-1.624 (1.00)	-2.155** (0.50)	-2.737*** (0.50)
Y *(GDPphw)* *(Avg. lags)*	-1.841 (1.31)	-2.063 (1.31)	-2.616*** (0.31)	-2.748** (0.31)
$\boldsymbol{Y^2}$ *(GDPphw)* *(Avg. lags)*	-1.769 (0.90)	-2.008 (0.90)	-2.689*** (0.27)	-2.984*** (0.27)
$\boldsymbol{Y^3}$ *(GDPphw)* *(Avg. lags)*	-1.793 (1.31)	-1.212 (1.31)	-2.635*** (0.27)	-3.010*** (0.27)
C *(Avg. lags)*	-1.993 (0.40)	-2.137 (0.40)	-2.493*** (0.31)	-3.347*** (0.31)
P *(Avg. lags)*		-	-2.642*** (0.00)	-2.849*** (0.00)

*Note: t-bar statistics reported. *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level. Avg. lag (in bracket) denotes the average lag length of the underlying CADF test regressions.*

The bootstrap panel cointegration tests proposed by Westerlund (2007) have also been implemented to test the existence of a structural long-run relationship among the variables. These tests are general enough to accommodate cross-sectional dependence (Persyn and Westerlund, 2008). The Gt and Ga statistics test the null hypothesis of no cointegration for all cross-sectional units, with rejection implying cointegration for at least one unit, while the Pt and Pa statistics test the null hypothesis of no cointegration for all cross-sectional units, with rejection implying cointegration for the panel as a whole. Table 5 shows the computed values of the Westerlund cointegration tests. In general, the results show that the null hypothesis of no cointegration cannot be rejected.

Table 5. Cointegration tests for cross-sectionally dependent panels

Dependent variables	Independent Variables		Cointegration tests			
			Gt	Ga	Pt	Pa
Total Transport Energy *(absolute)*	***Y, Y²*, *Y³*, *C***	*Y=GDPpc*	-2.631	-2.143	-6.317	-1.518
	Y, Y², C	*Y=GDPpc*	-1.491	-2.738	-4.754	-1.615
	Y, Y², Y³	*Y=GDPpc*	-2.372*	-2.519	-3.407	-0.247
	Y, Y²	*Y=GDPpc*	-1.396	-3.752	-3.087	-0.279
Total Transport Energy *(per capita)*	***Y, Y², Y³, C***	*Y=GDPpc*	-2.914	-1.632	-11.093	-1.748
	Y, Y², C	*Y=GDPpc*	-2.833	-3.089	-7.974	-1.897
	Y, Y², Y³	*Y=GDPpc*	-2.955	-2.858	-8.470	-1.902
	Y, Y	*Y=GDPpc*	-2.673	-4.826	-9.784	-3.022
Household Transport Energy *(absolute)*	***Y, Y², Y³, C***	*Y=GDPpc*	-4.094	-0.770	-9.196	-0.957
	Y, Y², C	*Y=GDPpc*	-2.455	-1.575	-6.802	-1.132
	Y, Y², Y³	*Y=GDPpc*	-2.715	-1.845	-6.995	-1.988
	Y, Y²	*Y=GDPpc*	-2.753	-3.066	-8.196	-2.313
Household Transport Energy *(per capita)*	***Y, Y², Y³, C***	*Y=GDPpc*	-2.352	-1.900	-6.303	-1.131
	Y, Y², C	*Y=GDPpc*	-1.886	-3.209	-6.867	-2.607
	Y, Y², Y³	*Y=GDPpc*	-1.983*	-2.988	-5.822	-1.324
	Y, Y²	*Y=GDPpc*	-1.699	-3.479	-6.006	-2.692
Productive Transport Energy *(absolute)*	***Y, Y², Y³, C***	*Y=GDPpc*	-3.686**	-1.707	-8.874	-2.058
	Y, Y², C	*Y=GDPpc*	-2.694*	-2.257	-7.141	-0.713
	Y, Y², Y³	*Y=GDPpc*	-2.694**	-2.257	-7.141	-0.713
	Y, Y²	*Y=GDPpc*	-1.920*	-3.614	-5.007	-0.645
Productive Transport Energy *(per capita)*	***Y, Y², Y³, C***	*Y=GDPpc*	-3.330*	-1.801	-7.504	-1.835
	Y, Y², C	*Y=GDPpc*	-2.455**	-3.929	-12.713*	-3.027
	Y, Y², Y³	*Y=GDPpc*	-3.076**	-3.254	-10.152	-2.764
	Y, Y²	*Y=GDPpc*	-2.435**	-4.800	-12.475*	-3.091
Productive Transport Energy *(absolute)*	***Y, Y², Y³, C***	*Y=GDPphw*	-3.039	-2.375	-6.909	-1.419
	Y, Y², C	*Y=GDPphw*	-2.146*	-4.708*	-7.907	-2.104
	Y, Y², Y³	*Y=GDPphw*	-2.207*	-2.450	-5.601	-0.439
	Y, Y²	*Y=GDPphw*	-1.486	-2.973	-0.784	-0.046
Productive Transport Energy *(per hour worked)*	***Y, Y², Y³, C***	*Y=GDPphw*	-2.974	-2.243	-10.755	-2.070
	Y, Y², C	*Y=GDPphw*	-2.099*	-3.665	-10.458	-2.361
	Y, Y², Y	*Y=GDPphw*	-2.296*	-2.641	-8.638	-1.716
	Y, Y²	*Y=GDPphw*	-1.961*	-3.752	-9.565*	-1.841

*Notes: (1) The Westerlund (2007) tests take no cointegration as the null hypothesis, and the test regression is fitted with a constant and trend, zero lag and lead with the kernel bandwidth being set according to the rule $4(T/100)^{2/9}$. The p-values are for a one-sided test based on 400 bootstrap replications. *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level.*

Taking into account the results of the previous tests, which indicate that all series are I(1) in levels and therefore I(0) in differences, and that the null hypothesis of no cointegration cannot be rejected, the data have also been transformed into first differences. As in Anjum et al. (2014), this procedure is similar to reformulating the EKC in terms of long-run growth rates.

Using italics to indicate the deviations from the geometric mean of the sample and the symbol Δ to indicate first differences, it is possible to rewrite [1] as follows,

$$\Delta\bar{E}_{it} = \delta_2\Delta d2_t + \delta_3\Delta d3_t + \ \dots + \ \delta_T\Delta dT_t \ + \ \beta_1\Delta\bar{Y}_{it} \ + \beta_2\Delta\bar{Y}_{it}^2 \ + \ \beta_3\Delta\bar{Y}_{it}^3 + \ \gamma_1\Delta\bar{C}_{it} + + \gamma_2\Delta\bar{P}_{it} + e_{it} \qquad t=2 \dots T \qquad [3]$$

We can see that [3] contains the differences in the year dummies and does not contain an intercept. Indeed, according to Wooldridge (2013: 469), it is possible to estimate the first-differenced equation with an intercept and a single time-period dummy, with the estimates of β_j being identical in either formulation. In this case, the equation becomes much easier to estimate. Additionally, the inclusion of a dummy variable for each time period makes it possible to account for secular changes that are not being modeled (Wooldridge, 2013: 469). The new equation may be expressed as follows:

$$\Delta\bar{E}_{it} = \alpha_0 + \alpha_3 d3_t + \cdots + \alpha_T dT_t + \beta_1\Delta\bar{Y}_{it} + \beta_2\Delta\bar{Y}_{it}^2 + \beta_3\Delta\bar{Y}_{it}^3 + \gamma_1\Delta\bar{C}_{it} + \gamma_2\Delta\bar{P}_{it} + e_{it} \qquad t=2 \dots T \qquad [4]$$

Autocorrelation, heteroscedasticity and cross-sectional correlation were analyzed to determine the estimated model of Equation [4]. The Wooldridge (2002) test for autocorrelation, the Wald test for homoscedasticity, proposed in Greene (2000), and the Pesaran (2004) test for contemporaneous correlation were used. Hausman (1978) tests were also performed to test for fixed versus random effect.

4. RESULTS

4.1. *Estimates results without prices*

Tables 6 to 9 show the results of estimating [4] when using per capita transport energy consumption (or per worked hours, as appropriate) as proxies for the environmental impacts of transport, and without the price variable. The estimates are obtained using the feasible generalized least squares (FGLS) method and controlling for autocorrelation, heteroscedasticity and contemporaneous correlation, according to the results of the Wooldridge (2002) test for autocorrelation, the Wald test for homoscedasticity, proposed in Greene (2000), and the Pesaran (2004) test for contemporaneous correlation. Furthermore, all Hausman tests indicate that random effects are preferred to a fixed effects model.

Table 6 shows the results of estimating [4] when *E* represents total transport energy use in per capita terms, with total transport energy use being the sum of household and productive transport energy use. The results show that the β_1 coefficient is positive and significant. Therefore, in the central point of the sample the elasticity is positive. Accordingly, rises in GVApc increase energy use for transport. The other β coefficients are non-significant. Similar results are obtained when the cubic term is removed in order to find a better specification. Likewise, the results are very similar when considering absolute transport energy consumption instead of per capita values (Annex 1). Consequently, the results show that the EKC is not supported for total transport energy use. Instead, a linear relationship between the variables is observed. Additionally, the results show that the γ_1 coefficient (relative to the variable C) is negative and significant. Therefore, the economic structure of countries affects the total transport energy use, with the total transport energy use being lower in countries where agriculture has a higher share in the economy. It is worth noting that removing the C variable from the estimate does not notably affect the β coefficients' estimates. Therefore, the economic structure does not affect the relationship between total transport energy use and GVApc (Annex 2).

Table 6. Total Transport Energy EKC estimate *without price variable*
(Energy use in per capita terms)

$\Delta\overline{Tot\ E}$ =	*0.023*	$+0.810\Delta\bar{Y}$	$-0.012\Delta\bar{Y}^2$	$+0.001\Delta\bar{Y}^3$	$-0.974\Delta\bar{C}$
Std.Err.=	*0.002*	*0.075*	*0.036*	*0.011*	*0.245*
	*****	*****	*n.s.*	*n.s.*	*****
Number of groups= 27 *Time periods=14*	*Wald chi2(17)=* *4964.83****	*Shape:* *No EKC*			

*Note: *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level. The estimate includes time dummies as expressed in [4].*

Table 7 shows the results of estimating [4] when *E* represents household transport energy use in per capita terms. The results show that the β_1 coefficient is positive and significant, with a value of 1.177. Therefore, in the central point of the sample, the elasticity is positive and higher than one, denoting that rises in GVApc increase household energy use for transport more than proportionally. The other β coefficients are negative and significant. Likewise, the results are very similar when considering absolute transport energy use instead of per capita values (Annex 1). The turning point value was calculated assuming elasticity to be zero. The value of GVApc (in log) which make elasticity zero is 4.362, which is not reached by any sample country in the time period analyzed. Additionally, the results show that the γ_1 coefficient is significant. Therefore, the economic structure of countries again affects the transport energy use. But now the value is positive, indicating that the household transport energy use is higher in those countries where agriculture has a higher share in the economy. As stated in Velaga et al. (2012), many rural areas have limited or no connection to public transport. Urban areas, however, have better public services, which help to reduce the amount of private vehicle use and so lowers fuel consumption (Pongthanaisawan and Sorapipatana, 2010). Additionally, it is worth noting that removing the C variable does not change the β coefficients' values (Annex 2).

Table 7. Household Transport Energy EKC estimate *without price variable*
(Energy use in per capita terms)

$\Delta\overline{Househ.E}$ =	0.019	$+1.177\Delta\bar{Y}$	$-0.108\Delta\bar{Y}^2$	$-0.082\Delta\bar{Y}^3$	$+1.031\Delta\bar{C}$
Std.Err.=	*0.007*	*0.168*	*0.046*	*0.017*	*0.522*
	**	***	**	***	**
Number of groups= 27 Time periods=14	*Wald chi2(17)= 615.57****	*Shape: EKC*	*Calculated turning point= lnGVApc=4.362 ($\bar{Y}$=1.897)*		*Within the data range?: No*

*Note: *** denotes significance at the 1% level, ** at the 5% level * at the 10% level and n.s. no significance. The estimate includes time dummies as expressed in [4].*

Table 8 shows the results of estimating [4] when E represents productive transport energy use in per capita terms and Y is GVApc. The results show that the β_1 coefficient is again positive and significant, with a value of 0.612. The β_2 coefficient is not significant, while β_3 is positive and significant. Similar values of β_1 and β_3 are obtained when the squared term is removed. Likewise, the results are again very similar when considering absolute transport energy use instead of per capita values (Annex 1). Therefore, the results show that the EKC is not supported in this case, with a growing relationship being observed between the variables. As GVApc grows, the productive transport energy use grows and in increasing increments. Additionally, the results show that the γ_1 coefficient (relative to variable C) is negative and significant. The negative value may relate to an increase in transport activities when economies shift towards having bigger industrial and service sectors (Beltrán-Esteve and Picazo-Tadeo, 2015). Thus, economies with bigger industrial and service sectors tend to have a higher share of freight road and air transport, which increases energy use. According to Steenhof et al. (2006), this means that technical progress is unable to reduce energy intensity if the share of freight road transport increases.

Table 8. Productive Transport Energy EKC estimate *without price variable*
(Energy use in per capita terms)

$\Delta\overline{Prod.E}$ =	*0.052*	$+0.612\Delta\bar{Y}$	$+0.029\Delta\bar{Y}^2$	$+0.037\Delta\bar{Y}^3$	$-1.597\Delta\bar{C}$
Std. Err.=	*0.007*	*0.116*	*0.039*	*0.018*	*0.335*
	***	***	*n.s.*	**	***
Number of groups= 27 *Time periods=14*	*Wald chi2(17)=* *471.71****	*Shape:* *No EKC*			

*Note: *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level. The estimate includes time dummies as expressed in [4].*

The previous results support a concave shape, but the EKC turning point is not reached. Nevertheless, an exponential relationship is observed for productive transport energy use. As these effects are opposed, when total transport energy use is considered the relationship is linear.

Finally, Table 9 shows the results of estimating [4] when E represents productive transport energy use per hour worked and Y is GVAphw. GVAphw can thus be considered a measure of labor efficiency as well as efficiency due to variations in other productive factors and technical progress (Schreyer, 2001). Therefore, it is a productivity measure. The results show that the β_1 coefficient is positive and significant once again, while the β_2 coefficient is negative and significant (the cubic term has been eliminated due to lack of significance). The positive and negative sign of β_1 and β_2, respectively, do not change when absolute transport energy use is considered instead of per capita values (Annex 1). Nevertheless, the turning point is not reached by any sample country in the time period analyzed. Additionally, the results show that the γ_1 coefficient is not significant in the squared specification. Removing variable C from the estimate does not significantly change the values or the sign of β coefficients. Therefore, the economic structure does not seem to influence transport energy use when it is considered in productivity terms.

Table 9. Productive Transport Energy EKCs estimate *without price variable*
(Energy use and GVA in per work hours terms)

$\Delta\overline{Prod.Ephw}$ =	0.056	$+0.813\Delta\bar{Y}$	$-0.108\Delta\bar{Y}^2$	
Std.Err.=	0.006	0.184	0.044	
	***	***	**	
Number of groups= 27 Time periods=14	*Wald chi2(17)= 557.87****	*Shape: EKC*	*Calculated turning point= lnGVAphw=5.790 ($\bar{Y}$=3.763)*	*Within the data range?: No*

*Note: *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level. The estimate includes time dummies as expressed in [4].*

4.2. *Estimates results with prices*

Tables 10-13 show the estimates of [4] when using per capita transport energy consumption (or per worked hours) and the price variable is included in the EKC model specification. Panel data are now for 22 EU countries and the period 1996-2009 because of lack of price data for Czech Republic, Estonia, Hungary, Romania and Slovenia and for 1995. The feasible generalized least squares (FGLS) method was used, as before.

Tables 10-12 show the estimates of [4] for total, household and productive transport energy use in per capita terms. Tables 10 and 12 show that $\beta_1>0$ and $\beta_2<0$, and the cubic term is eliminated in both estimates due to lack of significance. Likewise, price coefficients (γ_2) are negative and significant, which indicates that price rises will reduce transport energy use. Additionally, it is worth noting that removing price from the estimates does not significantly alter the value of the other coefficients, though it is just a bit higher for β_1 coefficients, therefore considering price only move downwards the estimated curve (Annex 3). Tables 10 and 12 also show that γ_1 coefficients are both negative and significant. Therefore, the total and productive transport energy uses are lower in countries agriculture accounts for a higher share in the economy. As mentioned before, no significant changes are found in coefficients when the variable C is removed.

Table 11 shows that the cubic specification confirms that $\beta_1>0$, $\beta_2<0$ and $\beta_3<0$ for household transport energy use. It is worth noting that as $\beta_1>1$, energy grows more than proportionally to

GVApc in the central point of the sample. However, we should note that this growth tends to be lower for higher values. The results also show that the price coefficient is near zero and non-significant. Therefore, there is no evidence to show that price directly affects household transport energy use. Eliminating price from the estimate does not significantly affect the value of the rest of the coefficients. In addition, Table 11 shows that γ2 is positive and significant. As noted in sub-section 4.1, household transport energy use is higher when the share of agricultural employment in total national employment is higher. Finally, it is worth noting that the results are very similar when absolute transport energy use is considered instead of per capita values, in all of the previous estimates.

Table 10. Total Transport Energy EKC estimate *with price variable*
(Energy use in per capita terms)

$\Delta\overline{Tot.E}$ =	0.021	$+0.746\Delta\bar{Y}$	$-0.074\Delta\bar{Y}^2$	$-1.613\Delta\bar{C}$	$-0.001\Delta\bar{P}$
Std.Err.=	*0.005*	*0.096*	*0.027*	*0.377*	*0.001*
	***	***	**	***	**
Number of groups= 22 Time periods=13	*Wald chi2(16)= 2235.71****	*Shape: EKC*	*Calculated turning point= lnGVApc=7.828 ($\bar{Y}$=5.040)*		*Within the data range?: No*

*Note: *** denotes significance at the 1% level, ** at the 5% level * at the 10% level and n.s. no significance. The estimate includes time dummies as expressed in [4].*

Table 11. Household Transport Energy EKC estimate *with price variable*
(Energy use in per capita terms)

$\Delta\overline{Househ.E}$ =	0.011	$+1.488\Delta\bar{Y}$	$-0.140\Delta\bar{Y}^2$	$-0.103\Delta\bar{Y}^3$	$+2.233\Delta\bar{C}$
Std.Err.=	*0.006*	*0.144*	*0.040*	*0.025*	*0.806*
	*	***	***	***	***
Number of groups= 22 Time periods=13	*Wald chi2(16)= 934.71****	*Shape: EKC*	*Calculated turning point= lnGVApc=4.359 ($\bar{Y}$=1.871)*		*Within the data range?: No*

*Note: *** denotes significance at the 1% level, ** at the 5% level * at the 10% level and n.s. no significance. The estimate includes time dummies as expressed in [4].*

Table 12. Productive Transport Energy EKC estimate *with price variable*
(Energy use in per capita terms)

$\Delta\overline{Prod.E}$ =	-0.045	+0.631$\Delta\bar{Y}$	-0.098$\Delta\bar{Y}^2$	-1.910$\Delta\bar{C}$	-0.002$\Delta\bar{P}$
Std.Err.=	*0.011*	*0.172*	*0.042*	*0.426*	*(0.001)*
	***.	***	***.	**	***
Number of groups= 22 Time periods=13	*Wald chi2(16)= 1239.34****	*Shape: EKC*	*Calculated turning point= lnGVApc=5.908 ($\bar{Y}$=2.688)*		*Within the data range?: No*

*Note: *** denotes significance at the 1% level, ** at the 5% level * at the 10% level and n.s. no significance. The estimate includes time dummies as expressed in [4].*

The β estimate values shown in Tables 10-12 were used to calculate transport energy use elasticity according to [2] to determine if the turning point has been reached. Figure 3 displays the elasticity values of the total, household and productive transport energy per capita with respect to GVApc, for each GVApc level (in Naperian logs).

Figure 3. Estimated elasticity of total, household and productive transport energy use with respect to GVApc

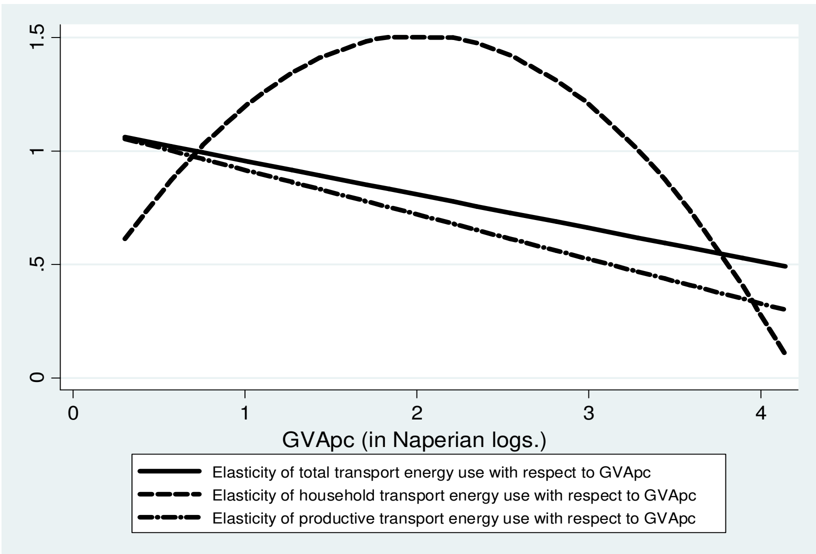


Figure 3 shows that the elasticity decreases from a GVApc threshold in the three cases, but in no case is the turning point of the ECK reached (the value of the elasticity is never zero). However, although the energy increases tend to be smaller for higher GVApc, they remain positive. Therefore, a growth of GVApc will not lead to a reduction of transport energy use. Figure 3 also shows that the elasticity values of household transport energy with respect to

GVApc are higher than 1 when the values of the Napierian logarithm of GVApc are between 0.8 and 3.5, approximately. Thus, as Steckel et al. (2013) argue, it is unlikely that lower income countries can develop without increasing their energy consumption. This statement can also be assumed to be true for the transport sector. Household income growth and economic growth will increase the use of private transport by households and this will lead to an increase in energy consumption in lower income EU countries.

Finally, it is worth noting that a squared equation fits better for productive transport energy use, while a cubic one seems better for households. When considering household and productive transport energy use as whole, a squared equation fits better, but now the β_1 estimate value is higher than that obtained for productive transport energy use. Nevertheless, the value does not exceed one, as in the estimates for households.

Table 13 shows the estimates of [4] for productive transport energy use in per hour worked terms, including the price variable. The cubic specification for productive transport energy with respect to GVAphw supports an N-shaped relationship as $\beta_1>0$, $\beta_2<0$, and the cubic coefficient is positive and significant. Therefore, the curve starts growing from a threshold level. Additionally, Table 13 shows that the price coefficient (γ_2) is negative and significant, showing that price increases will reduce transport energy use. In this case, the results indicate that the productive energy use is more sensible to price variation. In this case, removing the price variable from the estimate does not notably alter the estimated coefficients' values, although β_3 becomes non-significant. Finally, it is worth noting that economic structure is non-significant, therefore variable C has been removed. Nevertheless, the other estimated coefficient does not noticeably change when this variable is removed.

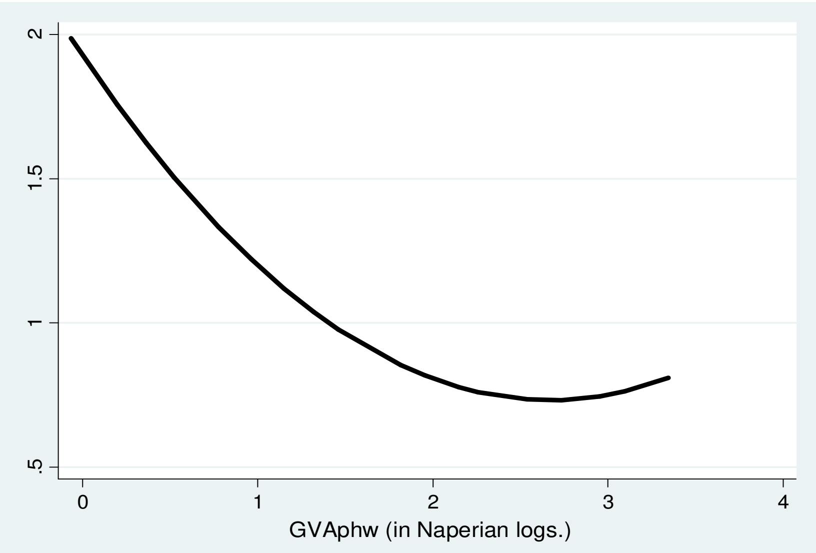
Table 13. Productive Transport Energy EKCs estimate *with price variable*
(Energy use and GVA in per work hours terms)

$\Delta\overline{Prod.Ephw}$ =	0.013	+0.802$\Delta\bar{Y}$	-0.109$\Delta\bar{Y}^2$	+0.056$\Delta\bar{Y}^3$	-	-0.003$\Delta\bar{P}$
Std.Err.=	0.007	0.125	0.064	0.026		(0.001)
	**	***	**	**.		***
Number of groups= 22 Time periods=13	*Wald chi2(16)= 1629.86****	*Shape: N-shaped*	*Calculated minimum value= lnGVAphw=2.670 ($\bar{Y}$=0.650)*			*Within the data range?: yes*

*Note: *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level. The estimate includes time dummies as expressed in [4].*

Figure 4 shows the elasticity values of productive transport energy use per hour worked, for each GVAphw level. These values relate economic productivity growth to productive transport energy use growth, thereby making it possible to evaluate transport production efficiency.

Figure 4. Estimated elasticity of Productive transport energy use with respect to GVAphw

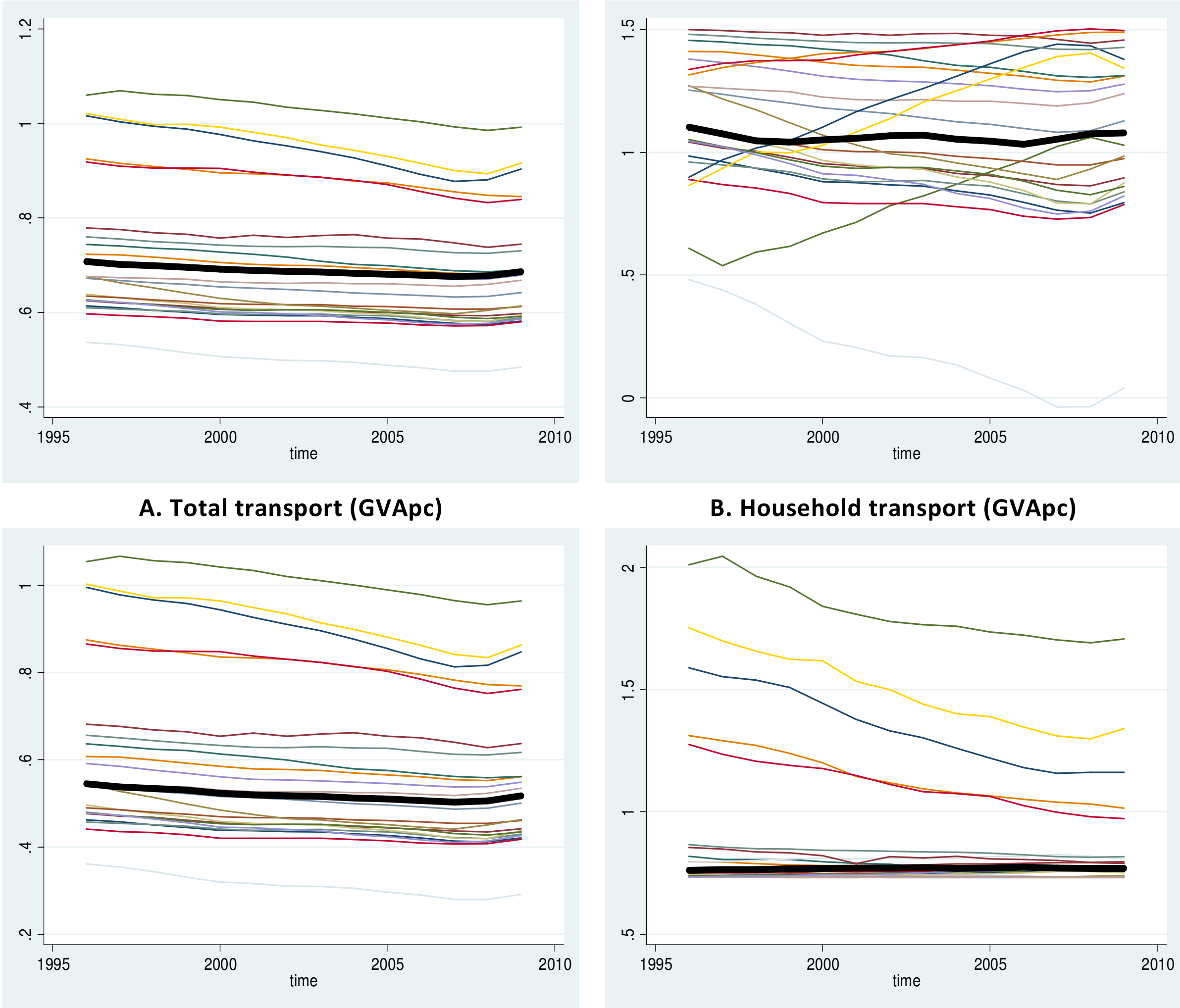


It can be seen that elasticity tends to decrease as GVAphw increases, to the point where they tend to stabilize or even grow slightly. Therefore, the estimation process reveals that higher productivity in the economy may be linked to savings in energy use, but these savings or efficiency gains could have a limit. It is thus possible that the efficiency gains are being offset by the additional international transport of imported goods (produced in 'dirty' industries in developing countries). Actually, as Kanemoto et al. (2014) point out, the increasingly stringent environmental regulatory regimes that have been implemented by a number of developed countries (such as those within the EU) to meet their CO_2 emissions reduction commitments allow them to shift emissions-intensive production offshore, thereby increasing the import of goods with high levels of embodied emissions.

4.3. Evolution of transport energy use elasticity by countries and country groups

The elasticity calculated from the previous estimates is constant neither over time nor between countries. Therefore, analyzing them will show differences between the countries and over time. Figure 5 shows the elasticity of total transport (Figure 5A), household transport (Figure 5B) and productive transport energy use per capita with respect to GVApc (Figure 5C), and productive transport energy use per hour worked with respect to GVAphw (Figure 5D), calculated from values shown in Tables 11-14 for each country in the period 1996-2009. The different lines represent the elasticity values for each country. These values are spread around a thicker black line that represents the cross medians of the values for each year.

Figure 5. Estimated elasticity of Total, Household and Productive transport energy use per capita, for each country (1996-2009)



A. Total transport (GVApc)

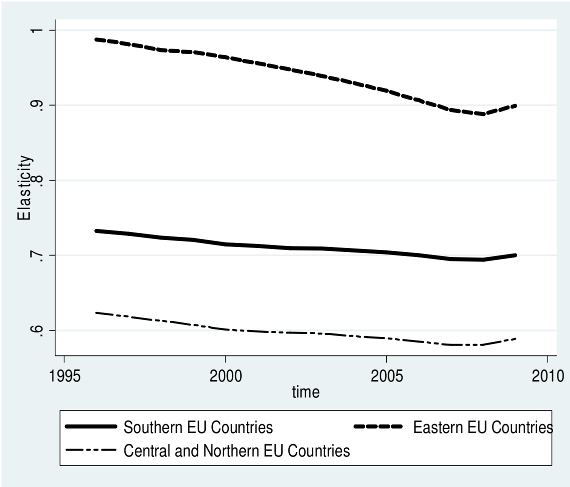
B. Household transport (GVApc)

C. Productive transport (GVApc)

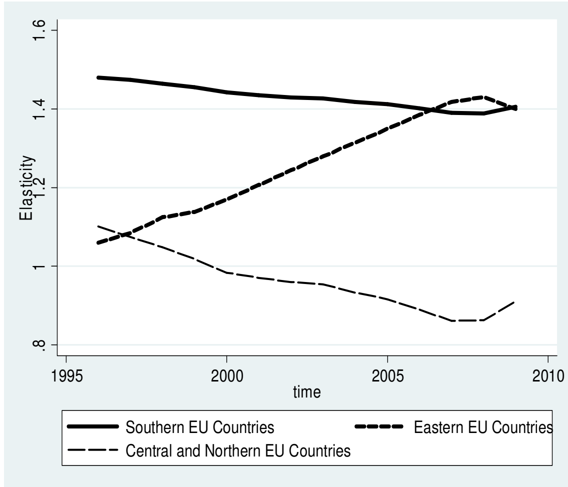
D. Productive transport (GVAphw)

In general, Figure 5 shows that the cross-median values of elasticity decrease slightly over the period, but countries show considerable differences. The cross-median values are approximately equal to one for household transport energy with respect to GVApc. It is worth noting that all elasticities are positive, with only Luxembourg's household transport elasticity being near zero (Figure 5B). Certain behavior patterns are detected in the following groups of countries: *i)* Central and Northern, *ii)* Eastern and *iii)* Southern or Mediterranean European countries. Figure 6 shows the average elasticity values for these country groups.

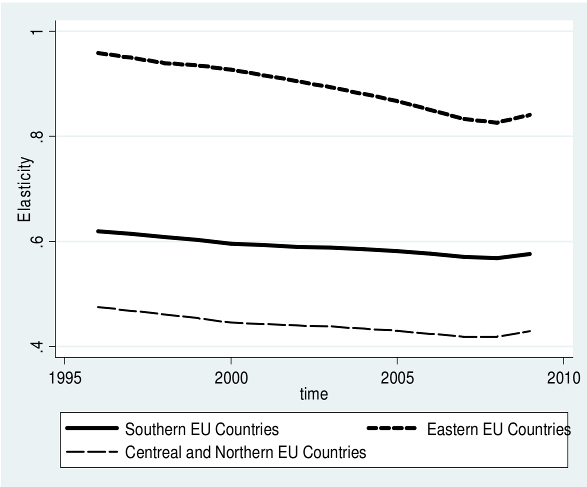
Figure 6. Estimated elasticity of Total, Household and Productive transport energy use per capita, for country groups (1996-2009)



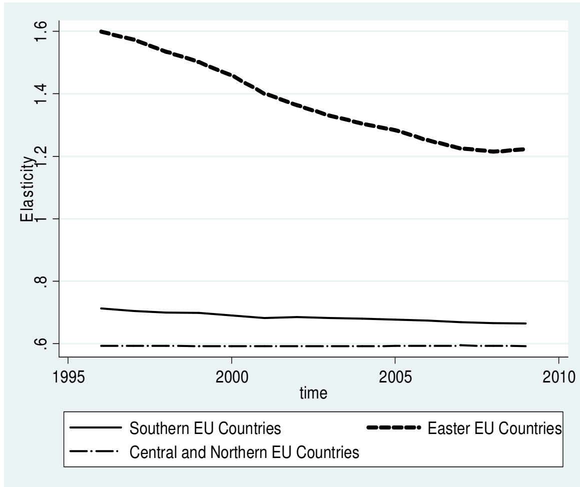
A. Total transport (GVApc)



B. Household transport (GVApc)



C. Productive transport (GVApc)



D. Productive transport (GVAphw)

Figure 6A shows the total transport energy use per capita elasticity trend. Eastern countries have higher values but also a higher negative trend. Southern, Central and Northern countries show a slightly negative trend, with the Central and Northern countries having the lowest elasticity values. This means that when GVApc increases, the relative growth in transport energy use is less for Central and Northern European countries. A similar pattern is found for productive transport energy use with respect to GVApc (Figure 6C), and for productive transport energy use with respect to GVAphw (Figure 6D), although in this last figure we can see that the elasticity for Central and Northern countries remains constant. Since these countries have higher GVAphw (as shown in

Figure 1), this could mean that they are close to the turning point shown in Figure 4, and therefore some energy savings could be achieved by implementing an energy efficiency policy in this sector.

This has relevant policy implications. It means that there is not much room in those (richer) countries for important reductions in productive transport energy use – and therefore little potential for energy efficiency policies. These results are in line with Pablo-Romero and Sanchez-Braza (2015), who find weak substitutability relationships between physical capital and energy use for the EU-15 countries, indicating that gains in energy efficiency are finite. Finally, if the aim is to reduce the environmental impacts and there is not much room to significantly reduce energy with efficiency policies, a possible viable alternative would be to introduce measures to change the energy mix – e.g. to promote the use of renewable fuels (less polluting) for use in the transport systems. In this regard, as identified by ADEME (2012), in 2009 there were only five countries with a relatively high share of alternative fuels: Germany, Slovakia, Austria, Sweden and France (between 6.5% and 7.5%), so a great deal more can be done to reduce emissions. Thus, a higher penetration of electric vehicles might be key to reinforcing the transition to less-polluting fuels in transport systems.

It is also worth noting that in Figure 6C elasticity is higher than one for Eastern countries, which indicates that productivity increases (GVAphw) are more than proportionally related to increases in energy per hour worked. This could mean that transport technology is not energy efficient or that the transport activities are less well organized in Eastern countries than in other EU countries. Finally, Figure 6B shows a growing trend in household transport energy elasticity for Eastern countries, which may be linked to the relative growth in GVA in these countries. Furthermore, this trend always has a value higher than one, which reflects an exponential growth in energy use. The greater number of private vehicles purchased and the reduction in the share of public transport may influence this energy behavior. It is worth noting in this respect that, on average, cars require four times more energy per passenger-km than public transport by rail or bus (ADEME, 2012). Note, too, the high household transport energy elasticity for Southern countries. Several factors influence this, including the rapid growth of car ownership in Cyprus and Greece (until 2007), the high car ownership ratio in Italy (more than 700 cars per 1000 inhabitants aged over 20), and the falling share of public transport in passenger traffic (ADEME, 2012). Finally, the negative elasticity trend for Southern and Central and Northern countries may reflect the regular decline in the average specific consumption of the car stock since 1995 (Lapillonne and Pollier, 2015).

5. CONCLUSIONS

In European countries, the transport sector has shown the fastest energy consumption growth and accounts for a growing share of the total emissions of final consumers. It is responsible for around a quarter of EU greenhouse gas emissions, which makes it the second biggest greenhouse gas-emitting sector after energy.

The effect of economic growth on transport final energy consumption in the EU countries has been analyzed in this article. Four types of transport energy EKCs were estimated for panel data of 27 EU countries in the period 1995-2009: Total transport energy use, Household transport energy use, Productive transport energy use with respect to GVApc and with respect to GVAphw.

Empirical results confirm that $\beta_1>0$, $\beta_2<0$ and $\beta_3<0$ for household transport energy use expressed in per capita terms and that $\beta_1>0$ and $\beta_2<0$ for productive transport energy use in per hour worked terms, when the price variable is omitted. Additionally, empirical results confirm that $\beta_1>0$, $\beta_2<0$ and $\beta_3<0$ for household transport energy use and that $\beta_1>0$ and $\beta_2<0$

for total and productive transport energy use, when expressed in per capita or per hour worked terms and including the price variable in the estimates, for the reduced sample of countries in the period 1996-2009. Nevertheless, when a cubic specification is used for productive transport energy use with respect to GVA per hour worked, the results show an N-shaped relationship.

Additionally, the estimate results show that transport energy use is negatively influenced by price growth. However, the price result is non-significant for household transport energy use. The results also show that omitting the prices variable in the EKC estimates has no noticeable effect on the β coefficients' values when considering per capita values. Prices only move up or down the estimated curve. Nevertheless, when considering per hour worked values for productive transport, the N-shaped curve is found if prices are included.

This study also shows that the turning point of the EKC is not reached in any case (the elasticity is never zero), i.e. although energy increases tend to be smaller for higher GVApc, the elasticity remains positive. Therefore, a growth of GVApc does not lead to lower transport energy use. Likewise, the results show that values of GVApc (in logs) between 0.8 and 3.5 are associated with household transport energy elasticity values higher than one. Economic growth should therefore increase the use of private transport by households and this will cause a rise in energy consumption in lower income EU countries. Thus, in future research it would be interesting to look at whether new, less polluting vehicles (particularly electric ones) might potentiate emissions reductions, which would help to substantiate the EKC hypothesis.

Over the period, the average values of transport energy use elasticity fall slightly, but notable differences are observed for individual countries. The relative increase in energy use is lower for Central and Northern countries when GVApc increases for total, household and productive transport energy use. Eastern countries have higher elasticity than Central and Northern countries for both household energy use and productive transport energy use with respect to

GVAphw. These results could be an outcome of the GVA growth experienced in these countries, or the increase in the number of private vehicles purchased might explain this energy behavior, too. Finally, the high household transport energy elasticity for Southern countries should also be noted. This could be caused by the rapid growth in car ownership in certain countries and the decreasing share of public transport in passenger traffic.

Finally, the results show that economic structure influences transport energy use when per capita values are considered. It was found that countries with a higher percentage of employment in agriculture have lower total and productive transport energy use, in per capita terms. Nevertheless, a higher percentage of agriculture employment tends to lead to higher household transport energy use. It is also worth noting that economic structure is non-significant when variables are considered in per hour worked terms, that is to say in productivity terms.

ACKNOWLEDGMENTS

This work has been framed under the Energy for Sustainability Initiative of the University of Coimbra and supported by the R&D Project EMSURE - Energy and Mobility for Sustainable Regions (CENTRO-07-0224-FEDER-002004). The first author acknowledges the financial support received from the ECO2014-56399-R Project of the Spanish Ministry of Economy and Competitiveness, the SEJ-132 project of the Andalusian Regional Government, and the "Cátedra de Economía de la Energía y del Medioambiente" (Chair of Energy and Environmental Economics) of the University of Seville and the "Fundació Roger Torné".

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ANNEX.1

Transport Energy EKCs estimates *with control and without price variable*
(Energy use in absolute terms)

	FGLS FD ***Total transport energy use***	*FGLS FD* ***Household transport energy use***	*FGLS FD* ***Productive transport energy use*** With respect to GVApc	*FGLS FD* ***Productive transport energy use*** With respect to GVA phw
β_1	0.710*** (0.063)	1.128*** (0.187)	0.502*** (0.142)	0.403*** (0.143)
β_2	0.043 (0.031)	-0.098** (0.038)	0.045 (0.053)	-0.073*** (0.034)
β_3	0.009 (0.117)	-0.087*** (0.013)	0.042*** (0.014)	-
γ_1	-1.089*** (0.239)	1.159** (0.554)	-1.516*** (0.300)	-0.673 (0.648)

*Note: Standard errors are shown in parenthesis, *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level. All estimates include time dummies for differences in the economic structure.*

ANNEX.2

Transport Energy EKCs estimates *without control and price variables*
(Energy use in per capita (worked hours) terms)

	FGLS FD ***Total transport energy use***	*FGLS FD* ***Household transport energy use***	*FGLS FD* ***Productive transport energy use*** With respect to GVApc	*FGLS FD* ***Productive transport energy use*** With respect to GVA phw
β_1	0.728*** (0.085)	1.19*** (0.181)	0.621*** (0.184)	0.813*** (0.184)
β_2	-0.024 (0.033)	-0.062 (0.101)	0.026 (0.034)	-0.108** (0.044)
β_3	0.003 (0.015)	-0.070** (0.036)	0.048*** (0.015)	-
γ_1	-	-	-	-

*Note: Standard errors are shown in parenthesis, *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level. All estimates include time dummies.*

ANNEX.3

Transport Energy EKCs estimates *with control and without price variables*
Reduced sample: 22 countries - 1996-2009
(Energy use in per capita (worked hours) terms)

	FGLS FD ***Total transport energy use***	*FGLS FD* ***Household transport energy use***	*FGLS FD* ***Productive transport energy use*** With respect to GVApc	*FGLS FD* ***Productive transport energy use*** With respect to GVA phw
β_1	0.958*** (0.062)	1.488*** (0.144)	0.664*** (0.143)	0.444** (0.185)
β_2	-0.029** (0.010)	-0.140*** (0.040)	-0.061** (0.031)	-0.136** (0.053)
β_3		-0.103*** (0.025)	-	0.038 (0.026)
γ_1	-0.870*** (0.308)	2.233** (0.806)	-1.481*** (0.824)	-

*Note: Standard errors are shown in parenthesis, *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level. All estimates include time dummies.*